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In re Application of:	)
	)
Yoshiyuki KAMATA et al.	)
	) Group Art Unit: 1773
Application No.: 10/702,439	)
	) Examiner: Bernatz, Kevin M.
Filed: November 7, 2003	)
	)
For: MAGNETIC RECORDING MEDIUM HAVING A PATTERNED SOFT MAGNETIC LAYER (As Amended)	)

Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

Sir:

SUBMISSION OF ENGLISH TRANSLATION OF PRIORITY DOCUMENT

On October 14, 2005, Applicants filed an Amendment in response to the Office Action dated June 16, 2005. In their Amendment, at page 10, in response to the rejection of claims under 35 U.S.C. § 102(e) as anticipated by Kikitsu et al. (U.S. Patent Pub. No. 2004/0131890), Applicants stated they were currently preparing an English translation of their priority Japanese Patent Application No. 2002-326057 for submission to the Patent Office to perfect their claim of priority pursuant to M.P.E.P. § 706.02(b). Applicants requested that the Examiner hold the rejection of claims 1 and 3-10 as anticipated by Kikitsu et al. in abeyance pending receipt of the translation of the priority document. Applicants have completed the translation of the priority document and submit the translation herewith to thereby perfect their claim of priority and eliminate Kikitsu et al. as prior art.

Applicants request Examiner's entry of the English translation of their priority Japanese Patent Application No. 2002-326057 and the reconsideration and withdrawal of the rejection under Section 102(e) based on Kikitsu et al.

Please grant any extensions of time required to enter this Submission and charge any additional required fees to our deposit account 06-0916.

Respectfully submitted,

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do hereby declare that I have a thorough knowledge of the Japanese and English languages and that the writing contained in the following pages is a correct translation of the attached Japanese Patent Office Certificate bearing the file reference

Japanese Patent Application No.2002-326057

Declared at Tokyo, Japan
This 26th day of October 2005

Sohbe SUZUKI

2002-326057

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[Title of Invention] MAGNETIC RECORDING MEDIUM AND METHOD FOR MANUFACTURE THEREOF
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[Title of the Invention] MAGNETIC RECORDING MEDIUM AND METHOD FOR MANUFACTURE THEREOF

[What is Claimed is]

[Claim 1] A magnetic recording medium comprising:

a non-magnetic substrate;

a soft magnetic layer formed on the non-magnetic substrate, the soft magnetic layer including a plurality of projected parts arranged regularly on a surface thereof and recessed parts surrounding each of the projected parts;

a ferromagnetic layer formed on the soft magnetic layer, the ferromagnetic layer including projected parts and recessed parts reflecting the projected parts and the recessed parts of the soft magnetic layer and having recording areas having perpendicular magnetic anisotropy and ferromagnetism, the recording areas being formed on an area of the projected parts of the ferromagnetic layer and being separated magnetically from their surroundings.

[Claim 2] The magnetic recording medium according to claim 1, wherein the non-magnetic substrate includes a plurality of projected parts arranged regularly on a surface thereof and recessed parts surrounding each of the projected parts, and the projected parts and recessed parts of the soft magnetic layer reflect the recessed parts and the projected parts of the non-magnetic substrate.

[Claim 3] The magnetic recording medium according to claim 1, wherein the non-magnetic substrate has a flat surface,

and the soft magnetic layer has the projected parts and the recessed parts on the surface thereof.

[Claim 4] The magnetic recording medium according to claim 3, wherein the soft magnetic layer comprises

a soft magnetic film having a flat surface; and

soft magnetic fine particles arranged regularly separately from each other on the soft magnetic film.

[Claim 5] The magnetic recording medium according to any one of claim 1 to 4, wherein the soft magnetic layer has such a thickness that a magnetic orientation thereof is stably uniform in an in-plane direction during writing and reading.

[Claim 6] The magnetic recording medium according to any one of claim 1 to 4, wherein a thickness L1 of the soft magnetic layer is at least twice a height L2 of the projected parts of the soft magnetic layer.

[Claim 7] A method for manufacture of a magnetic recording medium comprising:

forming a non-magnetic substrate including a plurality of projected parts arranged regularly on a surface thereof and recessed parts surrounding each of the projected part;

forming a soft magnetic layer on the non-magnetic substrate; and

forming a ferromagnetic layer having perpendicular magnetic anisotropy on the soft magnetic layer.

[Claim 8] A method for manufacture of a magnetic recording medium comprising:

forming a soft magnetic layer on a non-magnetic substrate;

forming a plurality of projected parts arranged regularly and recessed parts surrounding each projected part on a surface of the soft magnetic layer by using a press molding method; and

forming a ferromagnetic layer having perpendicular magnetic anisotropy on the soft magnetic layer after press molding.

[Claim 9] A method for manufacture of a magnetic recording medium comprising:

forming a soft magnetic film on a non-magnetic substrate;

arranging regularly soft magnetic fine particles including a composition common with the soft magnetic film separated from each other on the soft magnetic film; and

forming a ferromagnetic layer having perpendicular magnetic anisotropy on a surface on which the soft magnetic fine particles are arranged.

[Claim 10] A magnetic recording medium comprising:

a non-magnetic substrate having a plurality of projected parts arranged regularly on a surface thereof and recessed parts surrounding each of the projected parts;

a magnetic layer formed on the non-magnetic substrate, the magnetic layer including projected parts and recessed parts reflecting the projected parts and the recessed parts of the non-magnetic substrate, and having recording areas having perpendicular magnetic anisotropy and ferromagnetism, the recording areas being formed on an area of the projected parts of the non-magnetic substrate and being separated magnetically from their surroundings, a non-recording areas having soft

magnetism on an area excepting the recording area.

[Claim 11] A method for manufacture of a magnetic recording medium comprising:

forming a non-magnetic substrate including a plurality of projected parts arranged regularly on a surface thereof and recessed parts surrounding each projected part; and

forming an artificial lattice made of a ferromagnetic material having perpendicular magnetic anisotropy on the non-magnetic substrate.

[Detailed Description of the Invention]

[0001]

[Technical Field to Which the Invention Belongs]

The present invention relates to a high density magnetic recording technology and particularly to a patterned media capable of high density perpendicular magnetic recording and a method for manufacture thereof.

[0002]

In recent years, with the progress in areas of multimedia such as graphic, video, and sound data, the amount of data being searched per user has increased. Therefore, databases of larger capacity and higher speed are required. Meanwhile, due to improvements in the surface recording densities of magnetic recording media associated with increases in the recording capacity of Hard Disk Drives (HDDs), the recordable bit size of a magnetic recording medium is becoming extremely small, in the region of several dozen nm. In order to obtain reproduction output from this very fine recording bit, the greatest saturation magnetization and film thickness possible need to be secured for each bit. However, when the recording bit is miniaturized, the volume of switching unit (V) of each bit is reduced, giving rise to problems such as the loss of magnetized information caused by magnetic inversion due to thermal fluctuation.

[0003]

Generally, the influence of this thermal fluctuation increases as the value of $Ku \cdot V/kT$ decreases, where ku is an anisotropy constant, V is a volume of switching unit, k is the

Boltzmann's constant, and T is the absolute temperature. It is experientially said that when the Ku·V/kT is less than 100, magnetization reversal due to thermal fluctuation occurs. Magnetic anisotropic energy, which is required to keep the magnetization orientation of a magnetic particle to be in one direction, is expressed as the product of magnetic anisotropic energy density Ku and the volume V of the magnetic particle. If a value of the Magnetic anisotropic energy is as large as a value of the thermal fluctuation energy, the magnetization fluctuates with time and the phenomenon occurs that recorded information is lost.

[0004]

In a longitudinal-type magnetic recording medium, since the demagnetized field in recording bits in high recording density areas is strong, it is more likely to be affected by thermal fluctuation even if the magnetic particle size is relatively large. On the other hand, in a perpendicular-type magnetic recording medium, by growing magnetic particles in the film thickness direction, a volume of switching unit V can be increased as the particle size on the medium surface decreases, and thus the influence of thermal fluctuation can be suppressed. However, as high density of a magnetic medium is further promoted from now on, the thermal fluctuation resistance becomes limited even with the perpendicular magnetic recording type.

[0005]

As a medium for solving the problem of thermal fluctuation resistance, a magnetic recording medium called a "patterned

media" is drawing attention (for example, refer to Patent Document 1). The patterned media usually means a magnetic recording medium having a plurality of magnetic areas, which are to become recording bit units, and which are respectively formed independently from each other in a non-magnetic-material layer. In other words, the patterned media can be said to be a medium having a magnetically-continuous magnetic thin film divided into the size of the magnetic recording domain. In a usual patterned media, oxide such as SiO_2, Al_2O_3, or TiO_2, nitride such as Si_3N_4, AlN, or TiN, carbide such as TiC, or a boric compound such as BN is used as the non-magnetic-substance layer, and in this non-magnetic-substance layer, ferromagnetic material areas are formed selectively.

[0006]

Because the patterned media is a magnetic thin film divided into the size of the recording magnetic domain, the magnetization minimum unit volume V can be enlarged, and thus the problem of thermal fluctuation can be avoided. In a conventional continuous magnetic thin film, the number of magnetic particles used is allowed up to about 1000 grains per bit. However, the number of grains corresponding to a single bit decreases as the recording density increases. Since recording mark edges are determined by the grain boundaries, the grains need to be as small as possible in order to ensure S/N. Accordingly, in the conventional continuous magnetic film, V is forced to be smaller. On the other hand, in the patterned media, the edges of magnetic recording domains can be defined structurally.

Therefore, the improvement of S/N can be expected without making the V smaller.

[0007]

In the patterned media, because the ferromagnetic areas, serving as recording bit units, are respectively formed independently from each other, interference between recording bits can be prevented. This structure works for suppressing recording loss and noise generated due to bits located adjacently. Furthermore, domain wall displacement resistance increases by patterning, thereby making it possible to improve magnetic properties.

[0008]

[Patent Document 1]

Japanese Patent Application Laid-Open No. 2001-17609 (Fig. 1)

[0009]

[Patent Document 2]

Japanese Patent No. 3057586 (paragraph [0003], Fig. 1)

[0010]

[Problems to be Solved by the Invention]

As described above, because the patterned media can suppress magnetic inversion caused by thermal fluctuation, it is effective as a high-density magnetic recording medium, but the manufacturing process is more complex than the other magnetic recording media.

[0011]

FIGS. 11(a) to 11(e) show a general manufacturing method

of the patterned media used conventionally. According to the conventional producing method, first a ferromagnetic thin film layer 120 including ferromagnetic-materials, such as Fe, Co, Ni, etc., is formed on a substrate 110 (FIG. 11(a)), and the ferromagnetic thin film layer 120 is etched by ion-milling using a resist pattern 130 as a mask (FIG. 11(b)), and an independent pattern is formed for each recording bit (FIG. 11(c)). Further, the surface is coated with a non-magnetic layer 140 (FIG. 11(d)), and finally the surface is polished so as to expose a ferromagnetic pattern (FIG. 11(e)).

[0012]

Note that as shown in Fig. 11(b), because the ferromagnetic thin film layer 120 is made of a material to which etching is difficult to apply. Therefore, chemical etching using Reactive Ion Etching (RIE), etc., which is widely used in semiconductor processes, is difficult to be used, and thus, physical etching such as ion beam-milling is used instead.

[0013]

However, because ions accelerated by an electric field are sputtered onto the sample surface, the ion beam-milling damages the processed surface. This damage may cause noise during reproducing and recording. Therefore, in order to improve the magnetic characteristic, the development of a manufacturing method causing no damage is desired. Furthermore, there is a problem that manufacturing costs are great due to many process steps, and thus the development of a simpler manufacturing method is desired.

[0014]

On the other hand, a single magnetic pole head is employed as a writing/reading head suitable for the perpendicular-type magnetic recording medium. Also in the case of the perpendicular-type patterned magnetic recording media, this single magnetic pole head is preferably used during writing and reading. Although it is possible to write into very small areas with the single magnetic pole head having the magnetic pole made smaller to converge leak magnetic fields, a magnetic loop from the head to the medium and back to the head needs to be formed and magnetic flux needs to be guided efficiently through the coils of the head. Therefore, when using the single magnetic pole head, a soft magnetic layer, which is to be a path for the magnetic flux, is preferably arranged, as the base of a magnetic recording layer in order to form the magnetic loop (for example, refer to Patent Document 2).

[0015]

Therefore, when considering the structure and manufacturing method of the perpendicular-type patterned magnetic recording media, it is preferable to have a structure in which a soft magnetic layer, which is to be a path for the magnetic flux, is arranged between a recording layer and a non-magnetic substrate. It is also preferable to have a manufacturing method for such a structure. However, if the domain walls occur in the soft magnetic layer, they will cause noise during writing and reading.

[0016]

An object of the present invention is to provide a perpendicular-type patterned magnetic recording media low in noise and capable of writing/reading with a single magnetic pole head and a method for manufacture thereof.

[0017]

[Means for Solving the Problems]

A magnetic recording medium according to a first aspect of the present invention includes a non-magnetic substrate; a soft magnetic layer formed on the non-magnetic substrate and including a plurality of projected parts and recessed parts surrounding each projected part; and a ferromagnetic layer formed on the soft magnetic layer. The ferromagnetic layer includes projected parts and recessed parts reflecting the projected parts and the recessed parts of the soft magnetic layer. Recording areas having perpendicular magnetic anisotropy and ferromagnetism are formed on the projected parts of the ferromagnetic layer and are separated magnetically from their surroundings.

[0018]

Note that in the present invention, the ferromagnetic layer means a layer capable of having ferromagnetism according to the state of the laminated structure, etc., and the soft magnetic layer means a layer having soft magnetism.

[0019]

According to the first characteristic of a magnetic recording medium of the present invention, the ferromagnetic

layer is formed on the soft magnetic layer having the projected parts and recessed parts, and by the recess/projection shape effect, a patterned medium of which the projected parts are magnetically separated can be obtained. In a construction of the magnetic recording medium of the present invention, etching of the ferromagnetic layer is not necessary to form the patterned medium, whereby generation of noise based on damage due to etching can be suppressed. Further, because the soft magnetic layer is prepared as a base layer of the ferromagnetic layer, during recording and reproducing by use of the single magnetic pole head, a magnetic flux loop can be formed between the head and the medium, thus, high-density perpendicular magnetic recording become possible.

[0020]

In the magnetic recording medium of the present invention, the non-magnetic substrate may include a plurality of projected parts arranged regularly on a surface thereof and recessed parts surrounding each of the projected parts, and the projected parts and recessed parts of the soft magnetic layer may reflect the recessed parts and the projected parts of the non-magnetic substrate.

[0021]

Alternatively, the non-magnetic substrate may comprise a flat surface, and the soft magnetic layer may comprise the projected parts and the recessed parts only on an upper layer part. Moreover, the projected parts and recessed parts of the soft magnetic layer may be formed by a soft magnetic film having

a flat surface and soft magnetic fine particles regularly arranged with being separated from each other on the soft magnetic film.

[0022]

Further, in the magnetic recording medium of the present invention, the ferromagnetic layer may be an artificial lattice alternately laminating ferromagnetic films having different composition. Since characteristic of the artificial lattice depends on the state of the interfaces, an artificial lattice on the projected parts is magnetically separated more certainly from the artificial lattice of areas excepting the projected parts.

[0023]

In addition, in the magnetic recording medium of the present invention, it is preferable that the soft magnetic layer has such a thickness that a magnetic orientation thereof is stably uniform in a plane direction parallel to a surface of a substrate at least during recording and reproducing. Further, it is preferable that a thickness L1 is set to at least twice or more a height L2 of the projected parts and recessed parts of the surface of the soft magnetic layer. If the projected parts and recessed parts are present, a domain wall is apt to occur. However, by giving sufficient thickness, occurrence of the domain wall can be suppressed certainly, and a stable magnetic orientation in an in-plane direction can be provided during recording and reproducing, whereby generation of noise can be prevented.

[0024]

The first characteristic of a method for manufacturing a magnetic recording medium of the present invention is that the method comprises the steps of: forming a non-magnetic substrate including a plurality of projected parts arranged regularly on a surface thereof and recessed parts surrounding each of the projected parts; forming a soft magnetic layer on the non-magnetic substrate; and forming a ferromagnetic layer having perpendicular magnetic anisotropy on the soft magnetic layer. Further, it is preferable to use an injection molding method for forming the recessed parts and the projected parts on the non-magnetic substrate.

[0025]

According to the first characteristic of the method for manufacturing the magnetic recording medium of the present invention, the projected parts and recessed parts are formed on the non-magnetic substrate, and the soft magnetic layer and the ferromagnetic layer are formed thereon, whereby projected shapes and recessed shapes reflecting the projected parts and recessed parts of the non-magnetic substrate can be formed on each layer and in accordance with this shape effect, a recording area composed of a ferromagnetic substance separated magnetically from their surroundings can be formed at only the projected parts. That is, a patterned medium can be formed. Further, because the soft magnetic layer is prepared as a base layer of the ferromagnetic layer, during recording and reproducing by use of a single magnetic pole head, a magnetic

flux loop can be formed between a head and a medium. According to the method, a patterned medium can be formed without etching processes, therefore, a process is simplified and no damage due to etching is generated. Generation of noise due to damage can also be prevented. Moreover, because the projected parts and the recessed parts of the non-magnetic substrate are formed by injection-molding, the method is suitable in terms of mass productivity.

[0026]

The second characteristic of a method for manufacturing a magnetic recording medium of the present invention is that, the method comprises the steps of: forming a soft magnetic layer on a non-magnetic substrate; forming a plurality of projected parts arranged regularly and recessed parts surrounding each projected part on a surface of the soft magnetic layer by using a press molding method; and forming a ferromagnetic layer having perpendicular magnetic anisotropy on the soft magnetic layer on which the projected parts and recessed parts are formed.

[0027]

According to the second characteristic of the method for manufacturing the magnetic recording medium of the present invention,

the projected parts and recessed parts are formed on the soft magnetic layer, the ferromagnetic layer is formed thereon, whereby projected shapes and recessed shapes reflecting the projected parts and recessed parts of the soft magnetic layer can be formed on the ferromagnetic layer, in accordance with

this shape effect, a recording area composed of the ferromagnetic substance separated magnetically can be formed only on the projected parts. That is, according to the method, a patterned medium can be formed without etching processes, therefore, a process is simplified and no damage due to etching is generated. Occurrence of noise due to damage can also be prevented. Further, since the soft magnetic layer is prepared as a base layer of the ferromagnetic layer, during recording and reproducing by use of the single magnetic pole head, a magnetic flux loop can be formed between the head and the medium.

[0028]

The third characteristic of a method for manufacturing a magnetic recording medium of the present invention is that the method comprises the steps of : forming a soft magnetic film on the non-magnetic substrate; arranging regularly soft magnetic fine particles including a composition common with the soft magnetic film separated from each other on the soft magnetic film; and forming a ferromagnetic layer having perpendicular magnetic anisotropy on a surface on which the soft magnetic fine particles are arranged.

[0029]

According to the third characteristic of the method for manufacturing the magnetic recording medium of the present invention, the projected parts and recessed parts adjusted by a particle size and an arrangement can be formed on the soft magnetic layer by regularly arranging soft magnetic fine particles on the soft magnetic layer with being separated from

each other. Further, the ferromagnetic layer is formed thereon, whereby projected shapes and recessed shapes reflecting the projections and recesses of the soft magnetic layer can be formed on the ferromagnetic layer, and in accordance with this shape effect, the recording area composed of the ferromagnetic substance separated magnetically can be formed only on the projected parts, i.e., the soft magnetic fine particles. According to the method, a patterned medium can be formed without etching processes. A process is simplified and noise due to etching damage can be eliminated. Further, since the soft magnetic layer is prepared as a base layer of the ferromagnetic layer, during recording and reproducing by use of the single magnetic pole head, the magnetic flux loop is formed between the head and the medium.

[0030]

Further, in the method for manufacturing the magnetic recording medium having the first to third characteristics, it is preferable that the soft magnetic layer to be finally obtained has such a thickness that a magnetic orientation is stably uniform in a plane direction parallel to a surface of a substrate at least during recording and reproducing. More preferably, a thickness L1 of the soft magnetic layer is set to at least twice or more a height L2 of the projected parts and recessed parts of the soft magnetic layer. In this case, the soft magnetic layer has a sufficient thickness to provide a stable magnetic orientation in an in-plane direction during recording and reproducing, therefore, domain wall occurrence on the soft

magnetic layer can be suppressed, thus generation of noise can be suppressed. Occurrence of the domain wall due to influence of projected shapes and recessed shapes can be suppressed, thereby the stable magnetic orientation in the in-plane direction can be provided during recording and reproducing.

[0031]

A characteristic of the magnetic recording medium having the second characteristic of the present invention is that the medium has a plurality of projected parts arranged regularly on a surface thereof and recessed parts surrounding each of the projected parts; and a magnetic layer formed on the non-magnetic substrate. Further, the magnetic layer includes projected parts and recessed parts reflecting the projected parts and the recessed parts of the non-magnetic substrate, and having recording areas having perpendicular magnetic anisotropy and ferromagnetism on the projected parts.

[0032]

Further, a characteristic of the magnetic recording medium having the fourth characteristic of the present invention is the method for manufacturing the magnetic recording medium having the second characteristic and the method comprises the steps of: forming a non-magnetic substrate including a plurality of projected parts arranged regularly on a surface thereof and recessed parts surrounding each of the projected part; and forming an artificial lattice composed of a ferromagnetic material on the non-magnetic substrate. Further, it is preferable to use an injection molding method for forming the

recessed parts and the projected parts on the non-magnetic substrate.

[0033]

According to the magnetic recording medium having the second characteristic of the present invention and the method for manufacturing the magnetic recording medium having the fourth characteristic, the recording area composed of the ferromagnetic substance separated magnetically can be formed only on the projected parts. That is, according to the method, a patterned medium can be formed without etching processes. Generation of noise due to etching damage can be prevented. Further, since the recording areas made of ferromagnetic substance are surrounded by non-recording areas having soft magnetism, during recording and reproducing by use of a single magnetic pole head, a magnetic flux loop can be formed between the head and the medium. Moreover, according to this construction and manufacturing method, the recording areas made of the ferromagnetic substance and the non-recording area having soft magnetism are formed on the same layer, whereby a film forming step can be simplified.

[0034]

[Mode for Carrying out the Invention]

Preferred embodiments of the present invention will be described below with reference to the drawings.

[0035]

(First Embodiment)

A first embodiment relates to a magnetic recording medium and a method for manufacture thereof. In the magnetic recording

medium, a soft magnetic layer and a ferromagnetic layer of perpendicular magnetic anisotropy are serially laminated on a non-magnetic substrate having a plurality of projected parts arranged regularly and recessed parts surrounding each projected part on the surface thereof, in which the substrate is made by an injection molding method. According to the structure of this magnetic recording medium, projected parts and recessed parts reflecting the shape of the non-magnetic substrate are formed also on the soft magnetic layer and the ferromagnetic layer, and the so-called patterned media in which the projected parts of the ferromagnetic layer are specified only as recording areas.

[0036]

The structure of the magnetic recording medium, and the manufacturing method, of the first embodiment will be described specifically below.

[0037]

FIG. 1(a) is a cross-sectional view showing the structure of the magnetic recording medium according to the first embodiment, and FIGS. 2(a) and 2(b) are plan views thereof.

[0038]

As shown in FIG. 1(a), in the magnetic recording medium according to the first embodiment, a soft magnetic layer 20 and a ferromagnetic layer 30 having perpendicular magnetic anisotropy are serially laminated on a non-magnetic substrate 10 having a plurality of projected parts arranged regularly and recessed parts surrounding each projected part on the surface thereof. The soft magnetic layer 20 and the ferromagnetic layer

30 have projected parts and recessed parts reflecting recessed and projecting shapes of the nonmagnetic substrate 10.

[0039]

In this structure of the magnetic recording medium, since the ferromagnetic layer 30 covers the whole surface of the soft magnetic layer 20, recording bits are not physically isolated from one another. However, the projected and recessed shape loses magnetic interaction between the ferromagnetic layer 30 of the upper surface (referred to as simply projected parts hereafter) and the ferromagnetic layer 30 on sides and bottoms of the recessed parts (referred to as simply recessed parts hereafter). Accordingly, the projected part and the recessed parts are configured in a state of being magnetically isolated. That is, the structure functions as a so-called patterned media where only the projected parts of the ferromagnetic layer 30 serve as recording areas 30A which are intense in coercive force and the surrounding recesses of the ferromagnetic layer 30 serve as non-recording areas 30B. According to the structure of the magnetic recording medium of the first embodiment, without etching the ferromagnetic layer 30, a patterned media can be formed.

[0040]

Note that in order to magnetically divide the ferromagnetic layer formed on the projected parts with certainty, the film thickness of the ferromagnetic layer 30 is preferably set to be sufficiently thinner than a height of the projection parts (projection /recess height L2) of the soft magnetic layer 20.

For example, the film thickness of the ferromagnetic layer 30 is preferably set to be 1/2 to 1/4 of the projection/recess height L2 of the soft magnetic layer 20. For example, when a usual ferromagnetic thin film is used as the ferromagnetic layer 30 and the film thickness of the ferromagnetic layer 30 is 5 to 10 nm, the height of projected and recessed parts is preferably 10 to 20 nm or larger.

[0041]

Moreover, the ferromagnetic layer 30 is preferably formed by a multi-layer film having cobalt (Co), platinum (Pt) and the like laminated alternately, that is, in an artificial lattice made of metal. Since the characteristics of the artificial lattice depend on the state of the interfaces between the layers, a well-ordered laminated interface is not obtained on the ferromagnetic layer 30 of the side face of the projected and recessed parts, thereby dramatically degrading the magnetic properties. Therefore, the ferromagnetic recording areas 30A, having an intense coercive force of the projected part is magnetically divided by the existence of the ferromagnetic layer 30 of the side face which shows no ferromagnetism due to the degradation. Thus, the patterned media can be more easily, and with certainty, formed by using the artificial lattice.

[0042]

Note that by decreasing the area of the upper surface of the projected part, the state of a single magnetic domain which does not interact with adjacent bits and which has a uniform magnetization orientation can be achieved. For example, in

order to make each recording area 30A be in the single magnetic domain state, each recording area 30 is preferably set to 100nm or less, more preferably set to 80 nm or less.

[0043]

It is satisfactory that the recording areas 30A, which are the projected areas, are surrounded by recesses and arranged regularly, and the shape of a plan view of the recording areas 30A is not limited. As shown in FIG. 2(a), any shape can be taken, such as a rectangular, a circle as shown in FIG. 2(b), and an ellipse. Various array forms of the recording areas 30A are possible such as a tetragonal lattice as shown in FIG. 2(a) or a hexagonal lattice as shown in FIG. 2(b).

[0044]

On the other hand, because the magnetic recording medium according to the first embodiment has the soft magnetic layer 20 under the ferromagnetic layer 30, during recording and reproducing by use of the single magnetic pole head, a closed magnetic loop can be formed between the head and the medium.

[0045]

Note that in a magnetic recording medium having a soft magnetic layer, if domain walls occur in the soft magnetic layer, they will become a major cause of noise during recording and reproducing. In order to prevent the occurrence of domain walls in the soft magnetic layer, the magnetism orientation is preferably arranged in a constant direction, that is, arranged in an in-plane radial direction in a disk-type perpendicular magnetic recording medium, for example. The projected parts and

the recessed parts of the soft magnetic layer serve as a site pining for domain walls, to thereby produce the condition where domain walls are prone to be generated. The domain walls cause spike noise and therefore not desirable. On the other hand, in the magnetic recording medium according to the first embodiment, the generation of domain walls can be suppressed by setting the thickness L1 of the magnetic layer 20 to be sufficiently thick, preferably set to at least twice or more the height L2 of the recessed and projected parts on the surface. Therefore, during writing and reading by use of the single magnetic pole head, it is possible to obtain the magnetism orientation arranged in an in-plane direction of the soft magnetic layer 20, and the closed magnetic loop is formed between the head (not shown) and the medium as shown in FIG. 1(a), thereby enabling satisfactory high-density perpendicular magnetic recording.

[0046]

The material used for each layer will be described below.

[0047]

As the material of the non-magnetic substrate 10, the material suitable for the injection molding is preferably used. For example, thermoplastic resin is mentioned as the material. As thermoplastic resin, polycarbonate, polystyrene, styrene-based polymer alloy, acrylic resin (e.g. poly-methyl-methacrylate-based), polyvinyl chloride, polyester, nylon, ethylene-vinyl acetate resin, amorphous polyolefin, and the like can be listed. Thermosetting resin

can also be used other than above materials. In addition, epoxy resin, thermosetting polyurethane, unsaturated acrylic resin, unsaturated polyester, diethylene-glycol-bisallyl-carbonate resin, and the like are listed as the thermosetting resin. Furthermore, instead of resin, glass, especially low-melting glass can also be used. Polycarbonate is preferable in terms of high productivity, cost, moisture absorption resistance, etc. Amorphous polyolefin is preferable in terms of resistance to chemicals, moisture absorption resistance, etc.

[0048]

It is satisfactory that the soft magnetic layer 20 has a range of coercive force so that the magnetism orientation (spin orientation) is changed by the magnetic field of the single magnetic pole head during writing and reading, and the closed magnetic loop is formed. Generally, the force is set to preferably several kOe or less, more preferably set to 1 kOe or less, even more preferably set to 50 Oe or less.

[0049]

For example, as the soft magnetic layer 20, soft magnetic materials are mixed with any of the elements such as Fe, Ni, and Co in the composition, that is, such as CoFe, NiFe, CoZrNb, ferrite, silicon-iron, carbon-iron, and the like.

[0050]

A microstructure of the soft magnetic layer 20 is preferable in terms of clystallinity and microstructure control if constituted similarly to the ferromagnetic layer 30. However, when giving priority to the magnetic characteristic, another

structure can daringly be adopted. For example, the amorphous soft magnetic layer 20 can be combined with the crystalline ferromagnetic layer 30 or the converse can be considered. Moreover, the soft magnetic layer 20 may have a so-called granular structure where soft magnetic material particles exist in a non-magnetic matrix, or may be made up of a plurality of layers of different magnetic characteristics such as a multi-layer film of a soft magnetic layer and a non-magnetic layer.

[0051]

Note that the orientation of the magnetic anisotropy of the soft magnetic layer 20, excepting during writing and reading, may be perpendicular to the film surface, in an in-plane circumferential direction, in an in-plane radial direction, or a combination of these.

[0052]

As the ferromagnetic layer 30, a ferromagnetic material usually used in magnetic recording media at present, is used. That is, materials whose saturated magnetization Is and magnetic anisotropy are large are suitable. From this point of view, at least any one of Co, Pt, Sm, Fe, Ni, Cr, Mn, Bi, Al, and at least any one of the group consisting of the alloys of these metals, can be used. Among these metals, Co-alloy large in crystal magnetic anisotropy, especially an alloy having CoPt, SmCo, or CoCr as the base, or a regular alloy such as FePt or CoPt is preferable. Specifically, Co-Cr, Co-Pt, Co-Cr-Ta, Co-Cr-Pt, Co-Cr-Ta-Pt, $Fe_{50}Pt_{50}$, $Co_{50}Pt_{50}$, $Fe_{50}Pd_{50}$, $Co_{75}Pt_{25}$, etc are preferable. Furthermore, other than these alloys, a

material can be selected from a rare-earth/transition-metal alloy such as Tb-Fe, Tb-Fe-Co, Tb-Co, Gd-Tb-Fe-Co, Gd-Dy-Fe-Co, Nd-Fe-Co, or Nd-Tb-Fe-Co, a multi-layer film of a magnetic layer and a precious metal layer (artificial lattices such as Co/Pt or Co/Pd), a semimetal such as PtMnSb, a magnetic oxide such as Co-ferrite or Ba-ferrite.

[0053]

In order to control the magnetic properties of the ferromagnetic layer 30, an alloy of the above magnetic substance and at least any one or more element of Fe and Ni, which are magnetic elements, may be used as the ferromagnetic layer 30. Furthermore, additives for improving the magnetic characteristic may be added to these metals and alloys. Specifically, additives such as Cr, Nb, V, Ta, Mo, Ti, W, Hf, Cr, In, Zn, Al, Mg, Si, B, or a compound of these elements and at least any one element of oxygen, nitrogen, carbon, and hydrogen are preferable.

[0054]

As for the magnetic anisotropy of the ferromagnetic layer 30, as long as a perpendicular magnetic anisotropy component is major, an in-plane magnetic anisotropy component is allowed to exist. While the thickness of the ferromagnetic layer 30 is not especially limited, the thickness is preferably set to 100 nm or less when high density recording is taken into consideration, more preferably set to 50 nm or less, even more preferably set to 20 nm or less. Note that, when the thickness is 0.1 nm or less, it is difficult to form a continuous thin

film, and therefore it is not preferable. Meanwhile, in order to magnetically divide recording areas formed of projected parts and recessed parts, the thickness of the ferromagnetic layer is preferably thin, and the height of the recessed and projected parts are preferably large.

[0055]

Moreover, the ferromagnetic layer 30 is preferably a composite material made of magnetic particles and non-magnetic substances which exist therebetween. This is because high density magnetic recording is possible with specifying magnetic particles as inversion units. However, when recording areas are patterned, non-magnetic substances are not necessarily needed, and it may be a continuous, amorphous magnetic substance such as a rare-earth/transition-metal alloy.

[0056]

The method of manufacturing a magnetic recording medium according to the first embodiment will be described below with reference to FIGS. 3(a) to 3(c).

[0057]

First, as shown in FIG. 3(a), the non-magnetic substrate 10 having a plurality of projected parts arranged regularly and recessed parts surrounding each projected part on the surface thereof is formed by an injection molding. Specifically, an injection-moldable material such as a thermoplastic resin is used as the material of the non-magnetic substrate 10, then, molten resin is poured into a mold having a recessed and projected pattern formed thereon, and after cooling, it is taken out of

the mold. When forming a drum-type magnetic recording medium, a cylinder-type mold is used, and a cylindrical non-magnetic substrate 10 having fine projected parts and recessed parts formed on the outer surface is formed. Note that the height of the projected and recessed parts formed on the non-magnetic substrate 10 is set to e.g. 10 nm or larger, preferably set to 20 to 100 nm, and the dimension of the upper surface of the projected part is set to 100 nm square or less, preferably 80 nm square or less. In order to magnetically divide, the height of the recessed and projected parts is preferably equal or more to the length of one side of the rectangle of the upper surface of the projected part. However, when the aspect ratio of the projected parts becomes large, processing becomes difficult. Therefore, practically, the length of one side of the rectangle of the upper surface of the projected part is preferably set to equal to the height of the recessed and projected parts. For example, in the case where the upper surface of the projected part is 100 nm square, the height of the recessed and projected parts is set to 100 nm, and in the case of 40 nm square, the projection/recess height is set to 50 nm.

[0058]

The mold used for injection-molding having fine projected parts and recessed parts can be formed in the following manner. That is, a resist film is coated over a Si substrate or a resin cylinder, and a resist pattern is formed by EB (Electron Beam) exposure or FIB (Focused Ion Beam) processing; using the resist pattern as a mask, recess/projection pattern is formed on the

surface of the substrate by Ar-ion milling using the resist pattern as a mask, and further by sputtering Ni, etc., the surface is made conductive and the mold thereof is obtained by Ni-electroforming.

[0059]

However, because these pattern forming methods requires cost and time extremely, instead of the method of patterning a resist with EB exposure, a pattern intended to be the base of the mold is preferably formed using a method of forming a pattern of fine dots arranged regularly on a substrate by using the self-organizing function of block copolymer. By controlling the molecular weight, di-block polymer can easily form various arrangement structures of various sizes, and thus, is advantageous in terms of producing molds.

[0060]

Next, as shown in FIG. 3(b), the soft magnetic layer 20 is formed by use of a sputtering method on the non-magnetic substrate 10 formed by injection molding.

[0061]

Next, as shown in FIG. 3(c), the ferromagnetic layer 30 is formed on the soft magnetic layer 20 having recesses and projections. Note that artificial lattice is preferably formed as a ferromagnetic layer 30.

[0062]

In the above process, since the projected parts and recessed parts of the soft magnetic layer 20 are coated with the ferromagnetic layer 30, recording bits are not physically

isolated. However, the ferromagnetic layer 30 of the projected part is magnetically separated from the ferromagnetic layer 30 of the surrounding recessed part to form the recording areas 30A having a large coercive force at the projected part only. In this manner, the so-called patterned media can be obtained.

[0063]

According the manufacturing method of the magnetic recording medium of the first embodiment as described above, because non-magnetic substrates, having projected parts and recessed parts, are manufactured by the injection molding method, it is suitable for mass-production. Furthermore, because an etching process required for the conventional patterned media, is not necessary and a CMP process can also be omitted, and accordingly, the process can be widely simplified. Moreover, because an etching process is not necessary, the processing surface is free of any damage due to physical etching such as ion-milling. Noise due to etching damage does not occur, thereby improving the magnetic properties.

[0064]

Note that as shown in FIG. 1(b), in the magnetic recording medium, a nonmagnetic film 40 is formed on the ferromagnetic layer 30; the surface of the medium is flattened; and a protection film 50 is formed thereon. The flattening process is necessary since in R/W evaluation (read/write evaluation), HDI (Head Disk Interface) is important. Oxide such as SiO_2, Al_2O_3, or TiO_2, nitride such as Si_3N_4, AlN, or TiN, carbide such as TiC, or a boric compound such as BN can be used as the non-magnetic film

40 for flattening. Note that since it is difficult to fill the above-described non-magnetic film, in order to flatten the fine recesses and projections of nanometer level. A spin-coat method using SOG (Spin on Glass) is suitable for flattening. Since SOG is a liquid agent obtained by glass material dissolved in a solvent, and therefore, fills fine recesses on the substrate by spin-coating to flatten the surface uniformly. In addition, the solvent vaporizes several seconds after spin-coating to solidify. The SOG may be used as it is, but is preferably transformed into stable SiO_2 by applying heat treatment at a temperature of 450 °C or more.

[0065]

An example according to the first embodiment will be described below.

[0066]

(Example 1)

First, a cylindrical non-magnetic substrate 10 provided with projected parts and recessed parts was formed by an injection molding. A mold used for the injection molding was the one having a plurality of rectangular projected parts arranged regularly on the surface as shown in FIG. 2(a). This injection molding mold was formed by patterning a barrel-shaped cylinder by using an EB exposure method to obtain the mold thereof by Ni-electroforming. The upper surface of the rectangular projected part was set to 50 nm, and the height of the recesses and projections was set to 50 nm.

[0067]

Specifically, polycarbonate material was prepared as the non-magnetic substrate, and poured to a hopper of an injection molding machine. Then, injection molding was performed under conditions of the temperature of the mold at 125 °C, the temperature of resin at 340 °C, injection pressure at 30t, and cycle time at 12 seconds. In this way, a barrel-shaped polycarbonate cylinder with a size of 200 nm in diameter, and 700 nm in height, and which is expected to be a non-magnetic substrate 10 having recesses and projections on the surface thereof, was manufactured.

[0068]

Next, a CoZrNb film of 200 nm in thickness, which is the soft magnetic layer 20, was deposited by using a sputtering method applied on the surface of this barrel-shaped polycarbonate cylinder. Since the recesses/projections height L2 formed on the soft magnetic layer 20 is at least slightly less than the recesses/projections height 50 nm of the non-magnetic substrate. Therefore, in this condition, the condition that the thickness L1 of the soft magnetic layer 20 should be twice or more the recesses/projections height L2, was sufficiently satisfied.

[0069]

Subsequently, as the ferromagnetic layer 30, artificial lattice where Co and Pd films were laminated alternately was formed by a sputtering method. The thickness of the Co and Pd films were set to 0.3 nm and 0.7 nm respectively, and the number of the layers was set to ten. When artificial lattices of this kind were formed directly on a flat polycarbonate substrate

without forming the soft magnetic layer, squareness ratio was 0.8, and the coercive force was 2500 Oe, which were shown as magnetic characteristics.

[0070]

A SOG layer was formed on the ferromagnetic layer 30 to flatten the surface, and a C-protection film of 10 nm in thickness was further formed by a sputtering method.

[0071]

The magnetic recording medium obtained in this way was vanished under conditions of contact pressure of about 5 to 6g, disc rotation speed of 3000 rpm, slide speed of 1.25 mm/s, and five reciprocating motions, to the extent that a pulsed signal seemingly generated from the projected part goes out. In this way, R/W testing was conducted. When write-in was performed at a frequency of 1 MHz and with 40 mA, a reproduction signal of about 300 mV at the output of a pre-amplifier was obtained without occurrence of spike noise.

[0072]

(Example 2)

In example 2, a non-magnetic substrate was formed by an injection molding method using a mold having fine pattern formed thereon by use of the self-organizing function of di-block polymer. Other than the non-magnetic substrate, a magnetic recording medium was formed under the same conditions as in example 1.

[0073]

That is, a liquid agent mixed with PS-PMMA di-block

copolymer (PS: polystyrene ; PMMA: poly-methyl-methacrylate) was coated over a barrel-shaped cylinder to obtain a sea-islands structure in which island-like regions made of PMMA and a sea-like region made of PS are separated in a phase. These regions are exposed to ozone to vaporize PS selectively, to obtain a regular dot pattern of PMMA. Thereafter, ion-milling was performed using the dot pattern of PMMA as a mask; Ni is coated by sputtering over the surface of the barrel-shaped cylinder having recesses/projections formed thereon by etching; a conduction treatment is carried out thereon; and further an injection molding mold was formed by Ni-electroforming.

[0074]

Polycarbonate was injection-molded, and a pattern having projected parts of about 40 nm in diameter arranged at 80-nm pitches to be like a hexagonal lattice as shown in FIG. 2(b), was formed on the non-magnetic substrate 10, with the height of the projected parts being 50 nm.

[0075]

Next, a CoZrNb film of 200 nm in thickness, which is a soft magnetic layer, was deposited on the non-magnetic substrate by using the sputtering method as in example 1.

[0076]

Subsequently, artificial lattice where Co and Pd films were laminated alternately was formed by the sputtering method as the ferromagnetic layer 30. The thickness of the Co and Pd films were set to 0.3 nm and 0.7 nm respectively, and the number of the layers was set to ten.

[0077]

The magnetic recording medium obtained in this way was vanished under conditions of contact pressure of about 5 to 6g, disc rotation speed of 3000 rpm, slide speed of 1.25 mm/s, and five reciprocating motions, to the extent that a pulsed signal seemingly generated from the projected part goes out, and R/W test was conducted. When write-in was performed at a frequency of 1 MHz and with 40 mA, the reproduction signal of about 300 mV at the output of a pre-amplifier was obtained without the occurrence of spike noise.

[0078]

In the magnetic characteristic of the magnetic recording media, hardly any difference can be recognized between example 1 where an injection molding mold formed using EB exposure, which is a high cost process, was used and example 2 where an injection molding mold formed using the self-organizing function of di-block polymer, which is a low cost process, was used.

[0079]

(Example 3)

In example 3, a magnetic recording media in which the film thickness of the soft magnetic layer was set to be thinner than that of examples 1 and 2 was formed. Other than the film thickness of the soft magnetic layer, basic conditions were made same as in example 2.

[0080]

First, a pattern having projected parts of about 40 nm in diameter arranged at 80-nm pitches uniformly as shown in FIG.

2(b) was formed on a polycarbonate substrate using a injection molding mold formed by use of the patterning method using the self-organizing function of di-block polymer similarly to example 2. The recesses/projections height formed on the polycarbonate substrate, which is a non-magnetic substrate 10, was 50 nm.

[0081]

Next, a CoZrNb film of 80 nm in thickness, which is a soft magnetic layer, was formed on this soft magnetic layer by a sputtering method. That is, the condition is made such that the thickness L1 of the soft magnetic layer is thinner than the value twice the height L2 of the recesses/projections height on the soft magnetic layer.

[0082]

Subsequently, as the ferromagnetic layer 30, artificial lattice where Co and Pd films were laminated alternately was formed by the sputtering method. The thickness of the Co and Pd films were set to 0.3 nm and 0.7 nm respectively, and the number of the layers was set to ten. SOG was coated by spin-coat from the above to flatten the surface, and then a C-protection film of 10 nm in thickness was formed by sputtering.

[0083]

The magnetic recording medium obtained in this way was vanished under conditions of contact pressure of about 5 to 6g, disc rotation speed of 3000 rpm, slide speed of 1.25 mm/s, and five reciprocating motions, to the extent that a pulsed signal seemingly generated from the projected part goes out, and R/W

test was conducted. When write-in was performed at a frequency of 1 MHz and with 40 mA, it was confirmed that the reproduction signal was obtained. Note that in this example, little spike noise was observed and the reproduction signal was deteriorated compared with examples 1 and 2.

[0084]

When observing the magnetic patterns of the magnetic recording medium subjected to R/W evaluation by use of Magnetic Force Microscope (MFM), a pattern seemingly generated due to a domain wall of the CoZrNb film, which is a soft magnetic layer, was observed. This domain wall seems to cause spike noise. The domain wall occurs because the soft magnetic layer is so thin that the projected parts and the recessed parts become a pining site of the domain wall. From this result, in order to obtain a clear reproduction signal, the thickness L1 of the soft magnetic layer is at least twice the recesses/projections height L2 of the soft magnetic layer.

[0085]

(Comparative Example)

In a comparative example, a magnetic recording medium was formed by using a manufacturing method of a patterned media using the ion-milling etching method used conventionally shown in FIGS. 4(a) to 4(e).

[0086]

Specifically, a CoZrNb film of about 200 nm in thickness was formed as a soft magnetic layer 220 by a sputtering method on a flat polycarbonate substrate 210 as shown in FIG. 4(a).

Subsequently, artificial lattice where Co and Pd films were laminated alternately was formed by the sputtering method as a ferromagnetic layer 230 on the soft magnetic layer 220. The thickness of the Co and Pd films were set to 0.3 nm and 0.7 nm respectively, and the number of the layers was set to ten.

[0087]

As shown in FIG. 4(b), a photoresist 270 was coated thereon by about 150 nm in film thickness by use of a spin-coat method, and a nano-imprint mold is performed thereon using a Ni stamper 260 formed in the same way as the injection-molding mold used in example 2, to form projected parts and recessed parts on the photoresist 270. Thereafter, as shown in FIG. 4(c), the surface was etched by Ar-ion milling using the photoresist 270 as a mask. The remaining resist layer was removed by oxygen plasma to obtain the ferromagnetic layer 230 having projected parts and recessed parts as shown in FIG. 4(d).

[0088]

Next, when observing the surface by use of SEM (Scanning Electron Microscope), a lot of cracks like crevasses were observed on the soft magnetic layer. Furthermore, in observing of magnetic patterns by use of MFM, a pattern seemingly generated due to a domain wall was observed in the soft magnetic layer.

[0089]

Subsequently, as shown in FIG. 4(e), SOG was spin-coated on the ferromagnetic layer 230, and the surface was flattened by CMP processing, and then a carbon (C) protection film of 10 nm in thickness was formed by sputtering.

[0090]

R/W test was conducted. When write-in was performed at a frequency of 1 MHz and with 40 mA, no clear reproduction signal was obtained due to a large noise. A lot of spike noises were also observed. This is caused by damage due to the ion-milling process. It is considered that since the collision energy of Ar-ions by ion-milling is intense, the soft magnetic layer as well as the ferromagnetic layer was damaged, to generate cracks. These cracks had seemingly caused the occurrence of domain walls, causing large spike noises and no clear reproduction signal was obtained.

[0091]

As described above, when example 1 and example 2 are compared, it is clarified that etching damage is involved in a patterned media of the comparative example formed by the manufacturing method used conventionally, in which the ferromagnetic layer is etched by ion-milling, thereby generating a large noise. It was confirmed that in order to obtain a perpendicular magnetic recording medium of high S/N, the structure of the magnetic recording medium requiring no etching process according to the present embodiment is preferable.

[0092]

(Second Embodiment)

FIG. 5 shows a cross-sectional structure of a magnetic recording medium according to a second embodiment of the present invention. This magnetic recording medium, as shown in the figure, is obtained by forming a plurality of projected parts

arranged regularly and recesses surrounding each projected part on the surface on a soft magnetic layer 22 formed on a non-magnetic substrate 12 and then forming a ferromagnetic layer 32 having perpendicular magnetic anisotropy thereon.

[0093]

According to the structure of this magnetic recording medium, projected parts and recessed parts reflecting the shape of the magnetic layer are formed also in the ferromagnetic layer, and the so-called patterned media is formed specifying only the projected part of the ferromagnetic layer as the perpendicular recording area. That is, the structure is different from that of the first embodiment in that the non-magnetic substrate has no recesses and projections but the soft magnetic layer has projected parts and recessed parts formed thereon. Note that conditions not especially explained are the same as those in the first embodiment.

[0094]

In the structure of this magnetic recording medium, since the magnetic interactive force that acts between the projected part and the ferromagnetic layer 32 of recessed side part, and bottom, can be divided, a patterned media having independent recording areas 32A only in the projected parts can be formed. In plan view, the arrangement of the recording areas 32A takes a form of tetragonal lattice as shown in FIG. 2(a) or hexagonal lattice as shown in FIG. 2(b) similarly to the first embodiment.

[0095]

According to the structure of this magnetic recording

medium of the second embodiment, a patterned media can be formed without etching the ferromagnetic layer 32. The soft magnetic layer 22 prepared as a base layer of the ferromagnetic layer 32 becomes a path of a magnetic field during writing and reading by use of a single magnetic pole head, and thus a closed magnetic loop can be formed between the head (not shown) and the medium as shown in FIG. 5. Moreover, similarly to the first embodiment, the thickness L1 of the soft magnetic layer 22 is set to at least the thickness capable of arranging magnetism orientation stably in an in-plane direction, during writing and reading and preferably set to the thickness twice or more the recesses/projections height L2 on the surface of the soft magnetic layer. Thereby, the effects of the projected parts and recessed parts can be suppressed to prevent the occurrence of domain walls. Therefore, high-density perpendicular magnetic recording can be achieved.

[0096]

Next, the manufacturing method of a magnetic recording medium according to the second embodiment will be described with reference to FIGS. 6(a) to 6(c).

[0097]

First, as shown in FIG. 6(a), a soft magnetic layer 22 is deposited on a flat non-magnetic substrate 12 by use of a sputtering method.

[0098]

Subsequently, the soft magnetic layer 22 is press-molded (nano-imprinted) with a stamper 60, which is a hard mold having

projected parts and the recessed parts. Diamond, DLC (Diamond-Like Carbon), SiC, oxide such as SiO_2, Al_2O_3, TiO_2, Ta_2O_5, Cr_2O_3, ZrO_2, or CaO_2 is preferable as a hard mold material. In this way, the projected parts and the recessed parts as shown in FIG. 6(b) are formed on the soft magnetic layer 22. These projected parts and the recessed parts are constituted by a plurality of projections arranged regularly and recesses surrounding each projection.

[0099]

Note that the soft magnetic layer 22 is preferably a soft material exhibiting higher ductility and malleability so as to be subjected to nano-imprinting process. For example, Fe, artificial lattices of Fe/Pt, Fe_3Pt_1, or polymer layer with Fe, Ni and Co dispersed therein is suitable.

[0100]

Note that the recesses/projections height formed on the soft magnetic layer 22 is e.g. 10 nm or more, preferably 20 to 100 nm, and the upper surface dimension of the projected parts are set to 100 nm square or less, preferably set to 80 nm square or less. In order to magnetically divide, the recesses/projections height is preferably equal or more to one side of the rectangle of the upper surface of the projected part. However, when the aspect ratio of the projected part becomes large, it becomes difficult to process. Therefore, practically one side of the rectangle of the upper surface of the projected part is preferably almost equal to the recesses/projections height. For example, when the upper surface of the projected

part is 100 nm square, the recess/projection height is 100 nm, and when 40 nm square, the recess/projection height is 50 nm.

[0101]

Next, as shown in FIG. 6(c), a ferromagnetic layer 32 is formed on the soft magnetic layer 22 having the projected parts and the recessed parts formed thereon. The material of the ferromagnetic layer 32 can be made same as that of the magnetic recording medium according to the first embodiment.

[0102]

According to the manufacturing method of the magnetic recording medium of the second embodiment as described above, etching processes such as ion-milling required for the conventional patterned media forming process, can be eliminated, and CMP process can also be omitted, thereby greatly simplifying the process. Furthermore, ion-milling can be eliminated, thereby being free of any damage on the processing surface due to physical etching, and thus the magnetic characteristic can be improved.

[0103]

An example according to the second embodiment will be described below.

[0104]

(Example 4)

A nano-imprint mold is performed on a photoresist having the thickness of about 150 nm, which is formed on a SiC substrate by use of a Ni stamper, and thus, recess/projection pattern is formed on the photoresist. The Ni stamper is made by using a

phase-separation of PS-PMMA di-block copolymer which is used in example 2. Next, the SiC substrate was etched by RIE using the photoresist as a mask to produce a SiC stamper.

[0105]

Next, a flat Si substrate was prepared as a non-magnetic substrate, and a Fe film of about 300 nm in thickness was formed by a sputtering method as a soft magnetic layer on this Si substrate. The Fe film was directly nano-imprinted at a press pressure of 30t using the SiC stamper. The transferred recess/projection height was 15 nm.

[0106]

Subsequently, artificial lattice, in which a Co film and a Pd film were laminated ten times alternately by using sputtering method, was formed as the ferromagnetic layer. SOG was spin-coated thereon to flatten the surface, and then a C-protection film of 10 nm in thickness was formed by a sputtering method. In order to remove domain walls of Fe, the sample was introduced in a Helmholtz coil and magnetized at 15 kOe in a rotational direction of the disk.

[0107]

Thereafter, R/W test was conducted. When write-in operation was performed at a frequency of 1 MHz and with 40 mA, the reproduction signal was about 200 mV at the output of a pre-amplifier, and no occurrence of spike noise was observed.

[0108]

As described above, from the result of example 4, according to the magnetic recording medium of the second embodiment of

the present invention, patterned media having a satisfactory R/W characteristic could be formed more easily.

[0109]

(Third Embodiment)

FIG. 7 shows a cross-sectional structure of a magnetic recording medium according to a third embodiment of the present invention. This magnetic recording medium, as shown in the figure, has soft magnetic particles 23B, which has the same composition with the soft magnetic film 23A, arranged regularly on the flat, soft magnetic film 23A formed on a non-magnetic substrate 13, and the soft magnetic film 23A and the soft magnetic particles 23B are combined to constitute the soft magnetic layer 23 having projected and recessed parts thereon. Further, a ferromagnetic layer 33 having perpendicular magnetic anisotropy is formed on the soft magnetic layer 23.

[0110]

In the structure of this magnetic recording medium, since the magnetic interactive force which acts between the ferromagnetic layer 33A and the ferromagnetic layer 33B can be divided, the patterned media can be obtained. Wherein, the ferromagnetic layer 33A is formed on the upper surface of the soft magnetic particles 23B corresponding to the projected part, and the ferromagnetic layer 33B is formed on the side face of the soft magnetic particles 23B corresponding to the side face and bottom of the projected part, and on an exposure surface of the soft magnetic film 23A.

[0111]

The material of the soft magnetic film 23A and the ferromagnetic layer 33 can be made same with that of the magnetic recording medium according to the first embodiment. That is, , the soft magnetic material mixed with any one of the elements Fe, Ni, Co, such as CoFe, NiFe, CoZrNb, ferrite, silicon-iron, or carbon-iron is preferably used as the composition of the soft magnetic film 23A. As the soft magnetic particle 23B, the material mixed with the same composition with the soft magnetic film 23A such as Fe, Co, or Ni is used.

[0112]

The soft magnetic particles 23B are formed by use of a de-carbonyl reaction method, a super halide reduction method, or the like. In the de-carbonyl reaction method, carbonyl salt as a precursor such as $Co_2(Co)_8$, $Fe(Co)_5$, or $Ni(Co)_4$ and trialkyl phosphin (R_3P) are mixed and heated at high temperature to obtain fine particles such as Co, Fe, or Ni by de-carbonyl reaction. In the super halide reduction method, trialkyl phosphin (R_3P) is added to chrolide salt as a precursor such as $FeCl_3$, $FeCl_2$, $CoCl_2$, or $NiCl_2$ and particles such as Co, Fe, or Ni are obtained by reduction of the chrolide (Journal of Applied Physics, Vol. 85, No. 8, pp. 4325-4330, 15 April 1999). The diameter R of the fine particles depends on the length of the molecule chain of trialkyl phosphin to be added. For example, the diameter R can be made smaller by shortening the alkyl chain. In this way, the value of the diameter R can be adjusted.

[0113]

In order to form the magnetic recording medium of the third

embodiment, after the soft magnetic film 23A is formed on the non-magnetic substrate 13 by sputtering or the like, a colloid solution having soft magnetic particles formed by the above method dispersed therein is spin-coated over the soft magnetic film 23A, to form a mono-layer. The soft magnetic particles are arranged on the soft magnetic film 23A regularly by self-organizing function. Further, the ferromagnetic layer 33 may be formed thereon by sputtering.

[0114]

Note that in the magnetic recording medium of the third embodiment also, the film thickness L1 of the soft magnetic film 23A is preferably set to the thickness capable of arranging the magnetism orientation in the soft magnetic layer 23 during writing and reading, and more preferably set to twice or more the recess/projection height L2 of the soft magnetic layer 23, that is, set to twice or more the size of the soft magnetic particles 23B.

[0115]

According to the manufacturing method of the magnetic recording medium of the third embodiment as described above, magnetic interactive force which acts between the ferromagnetic layer 33 covering the upper layer part of the soft magnetic particles 23B, and the ferromagnetic layer 33 covering the side face part of the soft magnetic particle 23B and the soft magnetic film 23A, can be divided by the recess/projection formed by the soft magnetic film 23A and the soft magnetic particles 23B arranged thereon. Therefore, the patterned media having the

part covering the upper layer part of the soft magnetic particles 23B, that is, having an independent recording area 33A at the projected part of the ferromagnetic layer 33, can be formed. According to the above structure, the etching process such as ion-milling required for the conventional patterned media forming process, can be eliminated, and the CMP process can be omitted, thereby simplifying the process greatly. Moreover, because ion-milling is not necessary, the surface to be processed is free of any damage due to physical etching, thereby enabling the improvement of the magnetic characteristic. Moreover, because the occurrence of domain walls is prevented in the soft magnetic layer, high-density perpendicular magnetic recording can be achieved by use of a single magnetic pole head.

[0116]

An example according to the third embodiment will be described below.

[0117]

(Example 5)

First, soft magnetic particles were formed using a super halide reduction method. $FeCl_2$ as a precursor, and 1 milli-mol of oleic acid and 20 milli-mol of n-octyl-ether for controlling distance between particles were mixed in a nitrogen atmosphere and heated at a temperature of 100 °C. Subsequently, 3 milli-mol of tributyl phosphin $[CH_3(CH_2)_3]_3P$ for controlling the diameter of particles is added and heated at a temperature of 200 °C. The particle diameter R of the fine particles depends on the length of the molecule chain of tributyl phosphin, and in this

case, the diameter R equals to 7 to 10 nm.

[0118]

Next, after adding 1 mil of di-octyl-ether and 2 milli-mol of super hydride ($LiBEt_3H$) while stirring the above-described solution, the solution was heated at a temperature of 200 °C for 20 minutes, and cooled to 60 °C or below. Through this reduction process, Fe fine particles whose surfaces are covered with alkyl chains were formed.

[0119]

Thereafter, ethanol is dripped onto the above solution until a precipitate began to be separated, and the solution containing the precipitate was centrifuged. Waxy magnetic particles were re-dispersed in 10 ml of hexane in which 0.1 to 0.5 ml of oleic acid was added, and by adding ethanol to improve flowability, a Fe-particle colloid solution was produced. Note that oleic acid is used for stabilizing the solution.

[0120]

Meanwhile, a flat Si substrate was prepared as the non-magnetic substrate 13, and a Fe film of about 200 nm in thickness was formed thereon by a sputtering method as the soft magnetic film 23A.

[0121]

The Fe fine particles colloid solution produced by the above method was spin-coated on the Fe film, and heated at 300 °C to make the organic matter evaporated and the Fe fine particles arranged on the Fe film.

[0122]

On the soft magnetic layer 23 composed of the Fe particles and the Fe film, artificial lattice where Co and Pd films were laminated alternately was formed as the ferromagnetic layer 33 by a sputtering method. The thickness of the Co and Pd films were set to 0.3 nm and 0.7 nm respectively, and the number of the layers was set to ten. Furthermore, SOG was spin-coated thereon to flatten the surface, and then a C-protection film of 10 nm in thickness was formed by a sputtering method. In order to remove domain walls of Fe, the sample was introduced in a Helmholtz coil and magnetized at 15 kOe in a rotational direction of the disk.

[0123]

Thereafter, R/W test was conducted. When write-in was performed at a frequency of 1 MHz and with 40 mA, the reproduction signal of about 300 mV at the output of a pre-amplifier was obtained, and no occurrence of spike noise was observed.

[0124]

The magnetic recording medium of example 5 showed S/N ratio higher than that of the magnetic recording media of examples 1 and 2. This shows that the projected parts and the recessed parts of the soft magnetic layer formed by soft magnetic particles of 7 to 10 nm separate surely the magnetic domains of the ferromagnetic layer formed by the artificial lattices.

[0125]

(Fourth Embodiment)

A magnetic recording medium according to a fourth embodiment uses a non-magnetic substrate having projected parts

and recessed parts formed thereon similarly to the first embodiment, and the fourth embodiment relates to the magnetic recording medium capable of producing a simpler manufacturing method.

[0126]

FIG. 8 shows the magnetic recording medium according to the fourth embodiment. This magnetic recording medium has continuous magnetic layers 80 formed on a non-magnetic substrate 14 having a plurality of projected parts arranged regularly and recessed parts surrounding each projected part on the surface thereof. Among these continuous magnetic layers 80, the magnetic layer 80 formed on the projected part of the non-magnetic substrate 14 serves as a recording area 34 showing perpendicular magnetic anisotropy and ferromagnetism. The magnetic layer 80 formed at the part other than the above areas, that is, formed at the side faces of the recessed parts and the bottom thereof serve as soft magnetic areas 24, which are non-recording areas.

[0127]

In order to perform perpendicular magnetic recording by use of a single magnetic head, a magnetic loop has to be formed between the medium and the head. However, a soft magnetic layer need not exist under recording areas made of ferromagnetic substance. Like the magnetic recording medium according to the fourth embodiment, as long as the soft magnetic areas 24 surround each recording area 34, the soft magnetic areas 24 can become a path of the magnetic flux to form a magnetic loop. Therefore, perpendicular magnetic recording by use of a single magnetic

pole head can be achieved.

[0128]

In order to form the structure of the magnetic recording medium according to the fourth embodiment, it is satisfactory that the non-magnetic substrate having the recesses/projections is formed by an injection molding method similarly to the first embodiment, and artificial lattice such as Co/Pd or Co/Pt is formed directly thereon. When forming a Co/Pt artificial lattice for example, a fine laminated structure can be obtained on the upper surface of the projection and then ferromagnetism is exhibited. On the other hand, the magnetic recording medium does not take a laminated structure on sides and bottoms of the recessed parts, and thus the ferromagnetism characteristic of the artificial lattice is not exhibited, but soft magnetism is exhibited. Therefore, the Co/Pt artificial lattice formed on the upper surface of the projected parts serve as the recording areas 34, and the Co/Pt artificial lattice of other than the above areas serve as the non-recording areas 24.

[0129]

According to the manufacturing method of the fourth embodiment, damage generated due to etching can be avoided and the number of films can be reduced, thereby simplifying the processes.

[0130]

An example according to the fourth embodiment will be described below.

[0131]

(Example 6)

First, a polycarbonate substrate having a plurality of projected parts arranged regularly and recessed parts surrounding each projected part thereon was formed by injection-molding with the same condition as that of example 2. That is, a mold having fine projected parts and recessed parts is formed using the self-organizing function of block copolymer, and using this mold, as shown in FIG. 2(b), a non-magnetic substrate 14 of a hexagonal lattice pattern of about 40 nm in the projected part and 80 nm in pitch, and made of polycarbonate of 50 nm in recess/projection height was formed.

[0132]

Subsequently, an artificial lattice where Co and Pd films were laminated alternately was formed by a sputtering method as a magnetic layer 80 on the surface of the polycarbonate substrate. The thickness of the Co and Pd films were set to 0.3 nm and 0.7 nm respectively, and the number of the layers was set to ten.

[0133]

SOG was spin-coated over this layer to flatten the surface, and then a C-protection film of 10 nm in thickness was formed by a sputtering method.

[0134]

R/W test was conducted. When write-in was performed at a frequency of 1 MHz and with 40 mA, the reproduction signal of about 200 mV at the output of a pre-amplifier was obtained, and no occurrence of spike noise was observed. The signal output

is slightly lower than that of the magnetic recording media of examples 1 and 2. However, a reproduction signal having a practically sufficient sensitivity was obtained.

[0135]

(Other Embodiments)

A magnetic recording medium according to another embodiment, serving as patterned media formed without going through etching process similarly to the above-described first to fourth embodiments; having a soft magnetic layer at least around the ferromagnetic layer; and capable of performing perpendicular magnetic recording by a single magnetic pole head, will be described below.

[0136]

FIGS. 9(a) and 9(b) show the magnetic recording medium according to the other embodiment. This magnetic recording medium has a ferromagnetic layer 35 provided on a non-magnetic substrate 15 and soft magnetic areas 25 formed by transforming the ferromagnetic layer 35 chemically. As shown in the perspective view of FIG. 9(b), the soft magnetic areas 25 are formed so as to surround a plurality of exposed recording areas 35A of the ferromagnetic layer 35. Each recording area 35A is preferably made to be an area completely independent each other, but by surrounding at least the upper part of the ferromagnetic layer 35 with the soft magnetic area 25 as shown in FIG. 9(b), each recording area 35A can be separated from each other magnetically.

[0137]

Note that the dimensions of each recording area 35A are set to 100 nm square or less, preferably 80 nm or less so that the recording area 35A is in a single magnetic domain state where the magnetism orientation is uniformly arranged in one direction. The recording area 35A can take various shapes such as a circle or an ellipse, not being limited to a rectangle.

[0138]

The method of manufacturing a magnetic recording medium shown in FIGS. 9(a) and 9(b) will be described below with reference to FIGS. 10(a) to 10(e).

[0139]

First, as shown in Fig. 10(a), the ferromagnetic layer 35 constituted by an artificial lattice such as Co/Pd is formed on a flat non-magnetic substrate 15 by a sputtering method. Next, as shown in FIG. 10(b), a photoresist 70 is spin-coated on the ferromagnetic layer 35, and projected parts and recessed parts are transferred onto the photoresist 70 by use of a stamper 60 and by a nano-imprint method. The same stamper used in example 4 can be used as a stamper 60.

[0140]

Next, as shown in FIG. 10(c), the remaining resist left on the bottoms of recesses of the photoresist 70 formed by use of the nano-imprint method is removed by ashing using oxygen plasma to expose the ferromagnetic layer 35.

[0141]

Furthermore, as shown in FIG. 10(d), it is irradiated by low mass rare gas ions accelerated electrically using the

photoresist 70 as a mask to make portions not covered by the resist be soft-magnetic. He^{+} and Ne^{+} are preferable as low mass rare gas ions. The low mass rare gas ions are used in order to prevent the ferromagnetic layer 35 from sputter etched during field acceleration. That is, the artificial lattice is irradiated by low-mass rare gas ions by field accelerating, the interface of the artificial lattice is damaged. Therefore, the ferromagnetism is not exhibited any more, and then the ferromagnetic layer 35 turns into the soft magnetic areas 25. Thereafter, the resist is removed by an oxygen asher and a patterned media shown in FIG. 10(e) can be obtained.

[0142]

According to the magnetic recording medium and the manufacturing method for it, the patterned media can be formed without requiring the ferromagnetic layer 35 to be etched, and thus noise generated due to etching damage can be avoided. Moreover, because the recording areas 35A are surrounded by the soft magnetic areas 25, during writing and reading by use of a single magnetic pole head, the soft magnetic areas 25 serve as a path of the magnetic flux, and a closed magnetic loop can be formed between the head and the medium. Thus, perpendicular magnetic recording can be performed. Furthermore, in this method, since projected parts and recessed parts are not formed on the surface of the magnetic recording medium, the flattening process can be omitted.

[0143]

An example according to the other embodiment will be

described below.

[0144]

(Example 7)

First, an artificial lattice where Co and Pd films were laminated alternately was formed by a sputtering method as the ferromagnetic layer 35 on a flat Si substrate, a non-magnetic substrate 15. The thickness of the Co and Pd films were set to 0.3 nm and 0.7 nm respectively, and the number of the layers was set to ten. The magnetic characteristic in the vertical direction of the ferromagnetic layer is 0.8 in squareness ratio and 2500 Oe in coercive force. Thereafter, a photoresist was spin-coated by about 150 nm in thickness. This photoresist was subjected to nano-imprinting process using a Ni stamper formed by the same method as the injection-molding mold of example 2, which is patterned using the phase-separation of PS-PMMA di-block copolymer to form projected parts and recessed parts.

[0145]

Next, the photoresist was etched by RIE for 20 seconds to remove remaining resist left on the bottoms of recesses. Thereafter, using this resist pattern as a mask, a He^+ ion beam was irradiated onto the exposed ferromagnetic layer at an acceleration voltage of 400 V, with an electrical current of 100 mA. Subsequently, the resist was removed by oxygen asher. A C-protection film of 10 nm in thickness was further formed by a sputtering method.

[0146]

R/W testing was conducted. When write-in was performed

at a frequency of 1 MHz and with 40 mA, the reproduction signal was about 200 mV at the output of a pre-amplifier. No occurrence of spike noise was observed.

[0147]

The magnetic recording media of the present invention, the manufacturing methods therefore, and the like have been described using the embodiments. However, the present invention is not limited to these embodiments. It is apparent to those skilled in the art that various improvements and substitutions can be made to the present invention.

[0148]

[Effect of the Invention]

As described above, according to the magnetic recording media and manufacturing methods of the present invention, magnetic recording media functioning as patterned media and excellent in the thermal fluctuation resistance can be produced using the simpler method without going through a process of etching the ferromagnetic layer. Noise generated due to the damage by etching and domain walls in the soft magnetic layer can be suppressed, and thus high-density perpendicular magnetic recording media with less noise can be provided.

[Brief Description of the Drawings]

[FIG. 1]

FIG. 1 is a cross-sectional view showing a magnetic recording medium according to a first embodiment of the present invention.

[FIG. 2]

FIG. 2 is a plan view of the magnetic recording medium according to the first embodiment of the present invention.

[FIG. 3]

FIGS. 3 is a cross-sectional view showing steps of a method for manufacture of the magnetic recording medium according to the first embodiment of the present invention.

[FIG. 4]

FIG. 4 is a cross-sectional view showing steps of a method for manufacture of the magnetic recording medium of a comparative example in the first embodiment of the present invention.

[FIG. 5]

FIG. 5 is a cross-sectional view of a magnetic recording medium according to a second embodiment of the present invention.

[FIG. 6]

FIG. 6 is a cross-sectional view showing steps of a method for manufacture of the magnetic recording medium according to the second embodiment of the present invention.

[FIG. 7]

FIG. 7 is a cross-sectional view of a magnetic recording medium according to a third embodiment of the present invention.

[FIG. 8]

FIG. 8 is a cross-sectional view of a magnetic recording medium according to a fourth embodiment of the present invention.

[FIG. 9]

FIG. 9(a) is a cross-sectional view of a magnetic recording medium according to another embodiment of the present invention, and FIG. 9(b) is a perspective view of the magnetic recording

medium according to the another embodiment.

[FIG. 10]

FIG. 10 is a cross-sectional view showing steps of a method for manufacture of the magnetic recording medium according to the another embodiment.

[FIG. 11]

FIG. 11 is a process view showing a method for manufacture of a patterned media used conventionally.

[Explanation of the Reference Numbers]

10, 12, 13, 14, 15 NON-MAGNETIC SUBSTRATE

20, 22, 23 24, 25 SOFT MAGNETIC LAYER

30, 32, 33, 34, 35 FERROMAGNETIC LAYER

30A, 32A, 33A, 34A, 35A RECORDING AREA

30B, 32B, 33B NON-RECORDING AREA

40 NONMAGNETIC FILM

50 PROTECTION FILM

60 STAMPER

23A SOFT MAGNETIC FILM

23B SOFT MAGNETIC PARTICLES

70 PHOTORESIST

80 MAGNETIC LAYER

[Name of Document] Abstract

[Abstract]

[Object] There is provided a patterned medium of perpendicular magnetic recording type recording capable of recording and reproducing by use of a single magnetic pole head with simple manufacturing steps.

[Solving Means] A magnetic recording medium includes a non-magnetic substrate; a soft magnetic layer which is formed on the non-magnetic substrate and includes a plurality of projected parts arranged on a surface thereof and recessed parts surrounding each of the projected parts; and a ferromagnetic layer which is formed on the soft magnetic layer and perpendicular magnetic recording areas formed on areas of the projected parts of the ferromagnetic layer and separated magnetically from their surroundings. The soft magnetic layer has such a thickness that a magnetic orientation thereof is stably uniform in a plane direction parallel to a surface of the substrate during recording and reproducing.

[Selected Figure] Fig. 1

[Name of Document] Drawings

[FIG. 1]

30A RECORDING AREA

30B NON-RECORDING AREA

30 FERROMAGNETIC LAYER

20 SOFT MAGNETIC LAYER

10 NON-MAGNETIC SUBSTRATE

50 PROTECTION FILM

40 NONMAGNETIC FILM

[FIG. 4]

ION MILLING

[FIG. 5]

32A RECORDING AREA

32B NON-RECORDING AREA

32 FERROMAGNETIC LAYER

22 SOFT MAGNETIC LAYER

12 NON-MAGNETIC SUBSTRATE

60 STAMPER

[FIG. 7]

33A RECORDING AREA

33B NON-RECORDING AREA

13 NON-MAGNETIC SUBSTRATE

23 SOFT MAGNETIC LAYER

23A SOFT MAGNETIC FILM

23B SOFT MAGNETIC PARTICLES

[FIG. 8]

14 NON-MAGNETIC SUBSTRATE

80 MAGNETIC LAYER

24 SOFT MAGNETIC AREA

34 RECORDING AREA

[FIG. 9]

25 SOFT MAGNETIC AREA

35 FERROMAGNETIC LAYER

15 NON-MAGNETIC SUBSTRATE

35A RECORDING AREA

[FIG. 11]

ION MILLING